

A DESIGN MANUAL
FOR CABINET FURNITURE

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*Furniture Development Council. Research and
Information Committee.*

A Design Manual for Cabinet Furniture

*Basic scientific principles
concerning its construction*

PUBLISHED ON BEHALF OF THE
FURNITURE DEVELOPMENT COUNCIL

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The Research and Information Committee of the Furniture Development Council is advised by a series of Technical Advisory Panels. This book is a result of part of the research programme guided by the Technical Advisory Panel on Structures, under the Chairmanship of Mr. L. W. L. Alston, of Alstons (Long Melford) Ltd.

FOREWORD

One of the most remarkable features of scientific research is its fruitful applicability in unexpected places. This is often illustrated when research gives us new and profitable insight into the old and familiar. There can be no more familiar object than a piece of cabinet furniture; and yet, in the following pages, we find that a modern scientific study of it has yielded new and advantageous ways of constructing it so as to obtain maximum rigidity. I remember perusing the original memoir, entitled "The Theoretical and Experimental Analysis of Cabinet Structures" by Mr. T. Kotas, on which this little book is based, and I am now delighted to see available this shortened version, written for a wider audience.

The work of Mr. Kotas has shown that there are basic principles that can be applied in various ways. In the past, the methods of constructing cabinet furniture have been developed by empirical methods so that the idea of having scientific principles that can be applied to furniture is new.

But let no one think that the scientist, even today, can displace the craftsman. Craftsmanship should be the optimum expression of science and technology. Here, then, is an example of the scientists' basic contribution to a partnership—and not to a displacement.

EDWARD APPLETON

16th October, 1958.

INTRODUCTION

This book has been written in an attempt to provide the designer with technical information in addition to that gained by experience and tradition. It gives him the basic scientific principles concerning the construction of cabinet furniture.

These basic principles have been evolved as a result of a research project carried out by the Research Department of the Furniture Development Council. They give the furniture designer the same kind of information that helps the architect when designing a roof truss. Mathematical analysis and experiment have now shown where and how much material should be placed so as to provide the maximum rigidity; it being assumed that rigidity is a desirable quality.

This is believed to be the first basic research applied to this craft industry, and, whilst some of the results may at first sight seem only to confirm the experience that has been handed down from craftsman to craftsman, the other parts of the work may be considered new.

There are two basic principles. The first principle lays down that all members of the frame of a wardrobe or similar article do not contribute to the rigidity of the whole in equal proportion. The frame members round the open face and the joints between them provide most of the rigidity and the other members of the frame simply hold the panels together. Simple and convincing ways of demonstrating this are suggested in the text.

The second principle is that a construction similar to a five-sided box can be made rigid by stiffening only one side of the box or cabinet, and simple ways of demonstrating this are also shown in the text. Furthermore, when a piece of cabinet furniture has been designed to incorporate these principles it is possible to calculate what the rigidity is likely to be.

The book has been divided into four chapters. In Chapter I there is a statement of the two principles with examples of how they might be applied. In Chapter II are instructions on how to measure rigidity of a complete cabinet, using simple equipment. In Chapter III several

detailed examples of articles incorporating the principles are illustrated and explained. A number of these are production models; others have been made as experimental wardrobes. Chapter IV contains a brief but more mathematical discussion on the various methods of stiffening and how rigidity can be calculated.

Research started in September 1953 and Mr. M. J. Merrick, Head of the Council's Research Department, was largely responsible for its successful completion. Mr. T. Kotas, who carried out the project itself, was awarded the degree of M.Sc. for the scientific analysis that formed the basis of the work, and Professor C. Gurney of University College, Cardiff, who provided research facilities, gave invaluable guidance and advice. Mr. Kotas's scientific analysis on which this book is based is described in "The Theoretical and Experimental Analysis of Cabinet Structures" (F.D.C. Research Report 6) by T. Kotas, M.Sc.

Special thanks are due to Dr. W. D. Douglas, who, until his recent retirement, was Head of the Research Department at Messrs. Harris Lebus Ltd. Dr. Douglas was probably the first man to attempt to apply the principles of structural engineering to furniture design in any significant manner. His help and advice during the work, and particularly his suggestions for the way in which it should be presented in book form, have been invaluable.

J. C. PRITCHARD

CHAPTER I

SIMPLE FACTS ABOUT CABINET RIGIDITY

I. WHAT HAPPENS WHEN A CABINET DISTORTS

An article of cabinet furniture can, in most cases, be considered as an open box. Such a box has the property that when it is pushed or pulled enough to alter its shape, it always deforms into the same shape, no matter what the directions of the loads applied to it (see Fig. 1).

When the distortion so produced is studied, it is found that all the faces of the box (including the open face) have twisted. Faces which were originally flat are now no longer flat. In addition, the open face, which may have been rectangular at the start, tends to become diamond shaped, the corner angles become greater and less than true right angles and straight members around the opening tend to become slightly curved.

Unless the distorting forces which are applied are large, the deformations which are produced will be comparatively small and may not be easy to detect without careful measurement, but their effects usually become evident in furniture from the binding of doors or from relative movement of door edges.

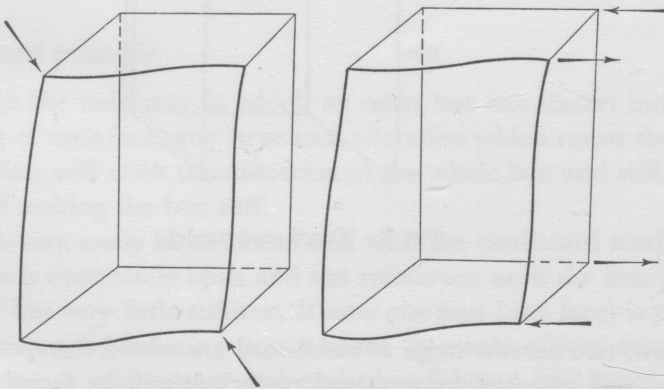


FIG. 1. The same shape results from different distorting forces.

The first principle

If an open box can deform in only one way and that way includes change of shape of the opening and also distortion of the joints and members which form the edge of the opening, then any structural alteration which stiffens these members will resist change of shape of the opening and will therefore make the box stiffer.

This method of stiffening is somewhat in line with traditional practice in which cabinets made with plywood are stiffened by using centre or side pilasters. Use of pilasters goes some way towards restricting the change of shape of the opening but, to be fully effective, the top and bottom members should be stiff enough to resist bending and the joints between these members and the pilasters should be rigid.

These effects can easily be demonstrated by making a simple cardboard model with five flat sides and one open face. The edge joints can be made with gummed paper strip (see Fig. 2). Much can be learned from a model of this nature. It will be found that, when handled, the box will distort easily. It will be seen that each flat face becomes twisted and that the opening distorts to a diamond shape similar to that shown in Fig. 1.

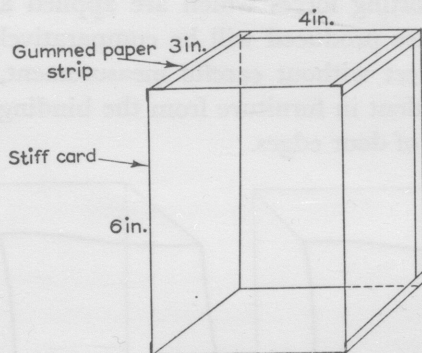


FIG. 2. Cardboard model.

If now, two narrow strips of cardboard are added to represent side pilasters (and attached by gummed paper), it will be found that the box has been stiffened considerably. Distortion of the opening can still

occur, however, by serpentine bending of the edges at the top and bottom of the opening and by change of angle at the joints where these edges meet the pilasters.

If a strip be now added to the model to prevent bending of the top edges and also to prevent change of the corner angles (see Fig. 3), it will be found that the whole box becomes remarkably stiff.

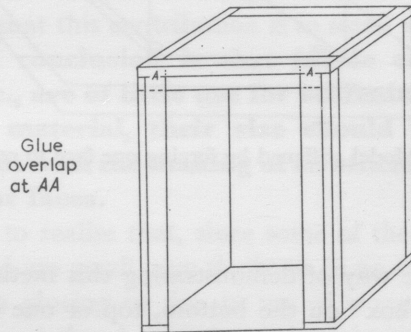


FIG. 3. Model with open face stiffened by pilasters and lintel.

These experiments suggest that one principle for making a piece of cabinet furniture rigid is to stiffen the face which contains the door or other opening so that the corner joints cannot change their angles and so that the side, top and bottom members cannot bend.

The second principle

Since the only way in which an open box can distort includes the twisting of each face, any structural alteration which resists the twisting of any face will resist the distortion of the whole box and will have the effect of making the box stiff.

This may easily be demonstrated with the cardboard model. While one face is completely open and not reinforced as in the first principle, the box has very little stiffness. If now one face (any face) is prevented from twisting by fastening it to a board by means of four drawing pins placed one at each corner and pushed well home (see Fig. 4) the box will be found to be stiff.

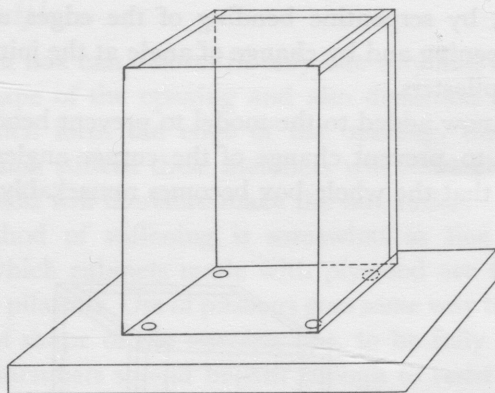


FIG. 4. Model stiffened by forcing one face to remain flat.

A more realistic way of demonstrating this method of stiffening is to build a "closed box" on the bottom, top or one side of the model. This is shown in Fig. 5. This "closed box" is extremely difficult to twist, and so serves a similar purpose to the board in Fig. 4.

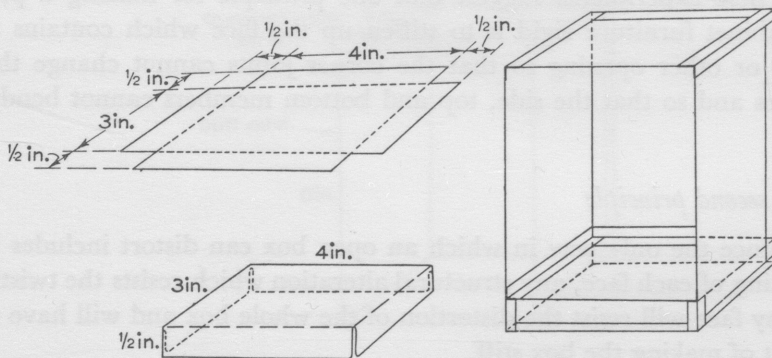


FIG. 5. Model stiffened by a closed box.

This suggests that a second general principle for stiffening cabinet furniture is to make at least one face very stiff in resisting twisting.

Economy in materials

Further examination of the cardboard model while it is being distorted will show that each corner edge where two panels are joined together remains straight even though the panels are twisting. This shows that, since corner members do not bend, the bending stiffness of such members does not contribute to the stiffness of the whole. These corner members do, however, twist and, in so far as they resist twisting, they contribute to the stiffness of the cabinet, but research measurements have shown that this contribution is so small as to be negligible.

The practical conclusion is that inside corner rails and stiles, linings, etc., are of little use for stiffening a cabinet and, for economy of material, their size should be as small as possible consistent with the making of an efficient joint between adjacent panels or faces.

It is important to realise that, since some of the distortions which have been described are small, any slackness in an important joint due to a local defect in glueing or due to use of a screwed instead of a glued joint might upset the above rules and might introduce unwanted flexibility in the cabinet.

2. STIFFENING THE OPEN FACE

Since an open faced box, of the type we are considering, cannot distort without the rectangular open face becoming lozenge or diamond shape, any stiffening of the open face which prevents the diagonals from changing in length will stiffen the whole box.

If forces are applied to opposite corners of an open face, tending to make one of the diagonals either longer or shorter, a diamond type distortion will be produced which is similar to that resulting from twisting the box.

Thus, in examining the structural suitability of various frames for the stiffening of the open face, we can conveniently select them on the basis of their effectiveness in resisting diagonal forces.

To stiffen a rectangular opening, the framework surrounding the opening should be such that two opposite corners are so rigidly connected that the distance between them cannot be changed except by large forces. For the stiffening to be effective, the minimum requirements are that two adjacent side members shall be stiff in bending and that the joint between them shall resist any change in angle.

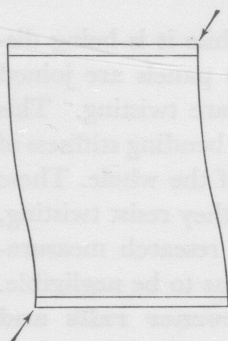


FIG. 6.

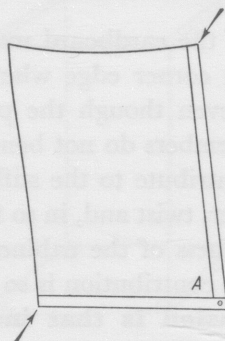


FIG. 7.

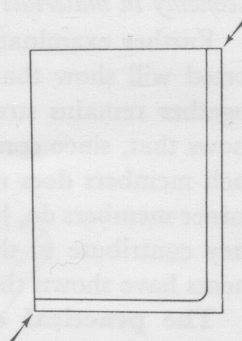


FIG. 8.

In Fig. 6 the stiffening fails because two adjacent sides are not stiff in bending.

In Fig. 7 the stiffening fails because the joint at A between the adjacent stiff members can change its angle.

In Fig. 8 the minimum requirements (of two stiff adjacent sides with a stiff joint between them) are met and the frame is effectively stiffened.

Naturally, added stiffness will be obtained by making all front edge members stiff in bending and all front corner joints stiff, assuming the open face is at the front. This does not apply, however, to the internal members or the joints between them since, as has been shown, the internal framing does not contribute to the stiffness of the box, but only serves to hold the sides together.

It will also be seen that corner brackets, which give stiff joints, will serve little useful purpose in stiffening the frame unless they are placed at weak joints between stiff members such as that at A.

Practical examples

One common and very effective means for stiffening an open face is the use of pilasters. In Fig. 9, the pilasters A and B may be regarded as side members very stiff in bending in the plane of the open face. In order to meet the minimum requirements for effective stiffening, either the top member C or the bottom member D (preferably both) should be stiff in bending and the joints between all these members should be as stiff as possible.

Sometimes the pilaster is central between two doors as in Fig. 10. In this case, the open face of the box may be regarded as having two openings side-by-side. Provided that each opening is stiffened, the whole face will be stiff. Again, the minimum requirement will be met if either the top or bottom cross member is stiff in bending and if the joint between this and the pilaster is really stiff.

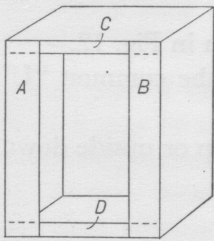


FIG. 9. Side pilasters.

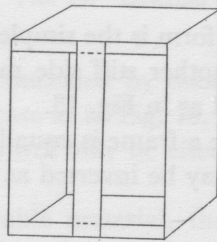


FIG. 10. Central pilaster.

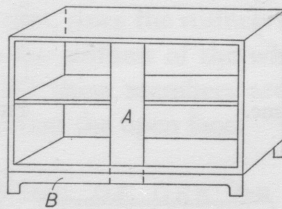


FIG. 11. Pilaster attached to apron.

A similar form of stiffening might be used for a sideboard as in Fig. 11, where the bottom member is made stiff in bending by the addition of an apron B. Again, it is essential that there shall be a really stiff joint between the pilaster A and the apron B.

Various typical forms for stiffening frames for open faces may be used. These are modifications of those already described and each can satisfy the minimum requirements for effective stiffening.

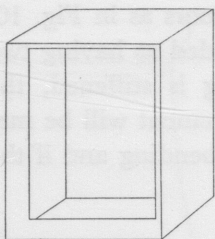


FIG. 12. "L" frame.

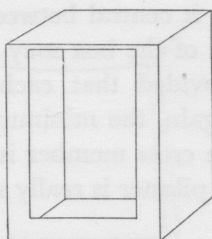


FIG. 13. "U" frame.

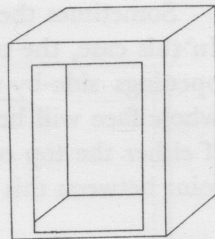


FIG. 14. Inverted "U".

One form is the simple "L" frame shown in Fig. 12.

If another stiff side member is added, the common "U" frame is obtained as in Fig. 13.

Since a frame is equally stiff right side up or upside down, the "U" frame may be inverted as in Fig. 14.

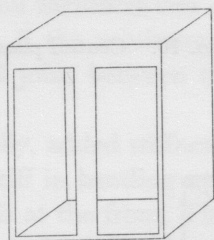


FIG. 15. "T" frame.

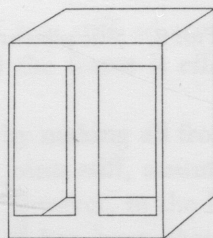


FIG. 16. "I" frame.

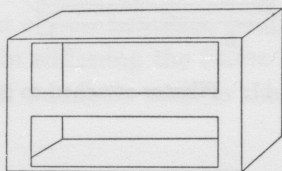


FIG. 17. "H" frame.

An inverted "U" frame may have the vertical member central in which case it becomes a "T" frame as in Fig. 15.

If the bottom member is stiff as well as the top member, it becomes an "I" frame as in Fig. 16.

If this frame is on its side, it becomes an "H" frame as in Fig. 17.

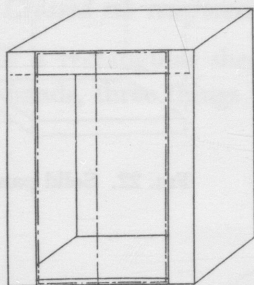


FIG. 18. Part of frame concealed by door.

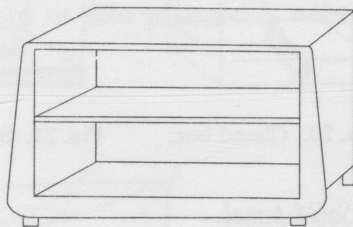


FIG. 19. External frame.

Sometimes part of the frame may be concealed by doors, etc., as in Fig. 18, or it may be external to the carcass as in Fig. 19.

It is again emphasised that these frames will only be effective if the joints between their members are rigid.

For the most efficient use of the available material, the bending stiffness of the various members surrounding the opening should be related to the type and proportions of the frame. These relations, for frames made from wood of solid rectangular cross section, are given in Chapter IV, together with other calculations related to the various front frame reinforcements.

It should be noted that, since the stiffness of internal frame members contributes so little to the stiffness of the whole box, it is of little importance whether or not these members are directly jointed to each other or to the frame round the open face.

3. STIFFENING OF ONE OR MORE SIDES

It has already been explained that distortion of an open faced box may be prevented by stiffening the framework round the open face or by preventing one (at least) of the other sides from twisting. The amount of stiffening which can be provided for the open face is frequently limited where the design demands the largest possible opening free from obstruction and where external stiffening cannot be used. In such cases the desirable stiffening of the box may be obtained by making one or more of the remaining faces stiff in resisting twisting.

Four methods for making a panel resist twisting forces are now described. These are: Solid panel, Closed box, Crossed rib reinforcement, and Pyramid reinforcement.

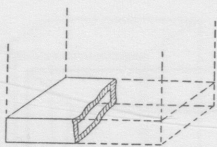


FIG. 20. Closed box.

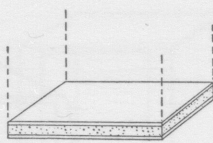


FIG. 21. Sandwich panel.

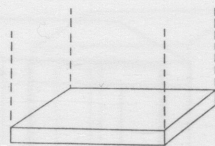


FIG. 22. Solid panel.

(a) *Solid panel*

The simplest form of panel which will resist twisting is one made from a thick, solid piece of material (Fig. 20). To save weight the panel may be of sandwich construction with a light core but with faces of stronger and more rigid material (Fig. 21). Where sandwich material is used, special attention should be given to making adequate joints between each face of the sandwich and the edges of adjoining panels.

(b) *Closed box*

A closed box has greater stiffening effect than a solid panel for a given weight of material, and the greater the depth of the box the more efficient it will be (Fig. 22). The closed box has not often been used for stiffening purposes but in many conventional designs it could be incorporated without any great alteration.

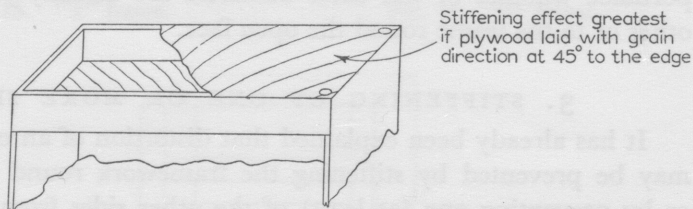


FIG. 23. Closed box with ply at 45°.

Wherever there is an unused space (as, for example, in a plinth) it may be possible to close the space with a panel of plywood and thus obtain the additional stiffening effect of a closed box (see Fig. 23). If plywood is used, its effect will be greatest if it is laid with the grain at an angle of 45° to the edges of the panel.

(c) *Crossed rib reinforcement*

If a rectangular sheet of cardboard or thin plywood is twisted in the hands, three things will be noticed.

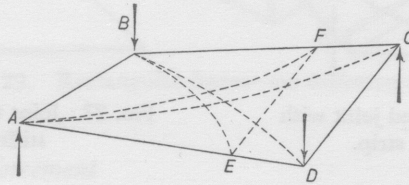


FIG. 24. Twisted panel.

Firstly, the edges (AB, AD, BC, CD in Fig. 24) remain straight; secondly, the diagonals (AC, BD) become curved in opposite directions; thirdly, that the lines on the panel which become most curved are those at 45° to the edge (such as AF, BE).

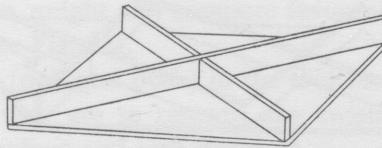


FIG. 25. Crossed rib reinforcement.

If two beams could be laid along the diagonals and attached to the panel at the centre and the ends, the curvature of the diagonals would be resisted and the panel would be greatly stiffened against twisting. (see Fig. 25). In practice, the beams could take the form of two intersecting ribs. The central joint should be so designed that neither rib is unduly weakened in bending. If the ribs are "halved" together, the rib that is cut away on the side furthest from the panel may need to be reinforced by a capping strip (Fig. 26), but an alternative method is to cut the notches so that only one-sixth of the depth is cut away on the rib that has the notch furthest from the panel (Fig. 27).

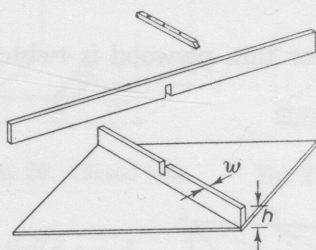


FIG. 26. Halved joint with capping strip.

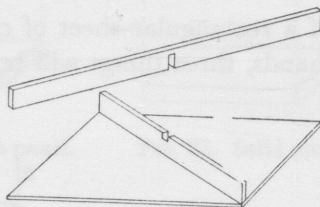


FIG. 27. Joint to give balanced stiffness.

Since the direction of the greatest curvature of the unstiffened panel is at 45° to the edges, the ribs are most effective on a square panel where they lie at 45° to the edge of the panel. Therefore, if the length of the panel is more than $1\frac{1}{2}$ times the width, it is better to treat the panel as if it were two panels with separate crossed-rib bracing for each, as shown in Fig. 28.

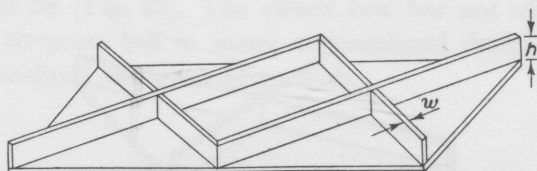


FIG. 28. Double crossed-rib reinforcement.

The stiffness of the structure increases rapidly with increase of the depth of the reinforcing ribs, but only proportionally to increase in their thickness. Thus, for example, if the depth, h , of the ribs is doubled, the stiffness increases nearly eight times, but if the thickness, w , is doubled, the stiffness is increased to less than twice its original value. This is explained in Chapter IV.

It may also be noted that, as the edges of the unstiffened panel remain straight when the panel is twisted, ribs placed around the edges of a panel, for instance, in the form of rectangular framing, or an open plinth, do practically nothing to prevent twisting of the panel (see Fig. 29).

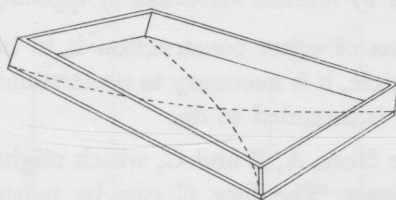


FIG. 29. Rectangular frame—no stiffening effect.

(d) Pyramid reinforcement

It has already been pointed out that when a panel is twisted its four corners cease to be in the same plane. If these corners could be forced to remain in the same plane, therefore, it would not be possible to twist the panel. A further method of doing this is the pyramid reinforcement, shown in Fig. 30. This reinforcement consists of four inclined members meeting at a point and resembling the edges of a pyramid. The free ends of the members are firmly anchored to the four corners of the panel. Provided the angle between each member and the panel is at least 20° (a slope of 1 in $2\frac{3}{4}$), the stiffening effect of this type of structure for a given weight can compare favourably with other forms of reinforcement (see Fig. 31).

Since the forces (pull and push) in the four inclined members must be considerable if they are to restrain any twisting of the panel, all the joints must be robust and well designed.

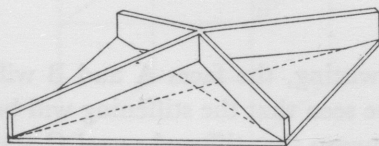


FIG. 30. Pyramid bracing.

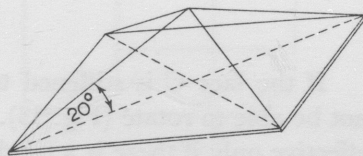


FIG. 31. Diagram of pyramid bracing.

This reinforcement is obviously something of a challenge to the ingenuity of the production engineer, but it is included here as a means of achieving stiffness with greatest economy of material.

(e) *Twist is caused by relative movement of opposing faces*

If the closed box or other construction is to be used efficiently to stiffen a cabinet article, it is necessary to understand clearly and exactly what the stiffening is intended to do.

In Fig. 32 three faces, A, B and C, which might form part of a box or cabinet, are shown. The face C can be twisted by the attached panels A and B rotating in their own planes and in opposite directions. This is what happens when a cabinet deforms, although the motions in an actual article of furniture may be so small as to be not easily seen by the eye.

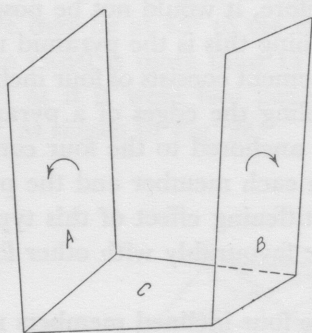


FIG. 32. Panel "C" twisted by rotation of panels "A" and "B".

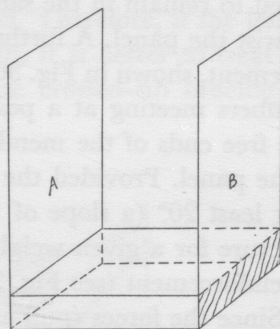


FIG. 33. Relative movement of "A" and "B" restricted.

If the face C is stiffened to resist twisting, the faces A and B will not be able to rotate (Fig. 33). It will be seen that the stiffening will be effective only if there is a rigid joint between the stiffened panel C and each of the panels A and B whose relative motion is being restrained.

It will also be seen that the stiffening need not necessarily extend over the whole face so long as there is still good attachment to the two opposing faces which it connects (see Fig. 34).

The stiffening structure may occupy any position between the opposing faces (Figs. 35 and 36).

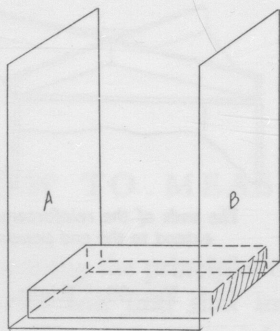


FIG. 34. Relative movement of "A" and "B" restricted.

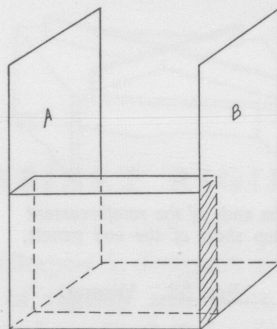


FIG. 35. Relative movement of "A" and "B" restricted.

If, however, the stiffening structure fails to make efficient contact with both the opposing faces (Fig. 37), its stiffening effect may be largely or completely lost.

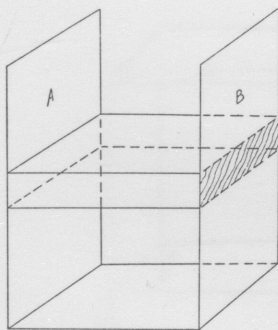


FIG. 36. Relative movement of "A" and "B" still restricted.

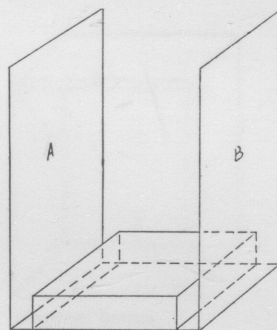
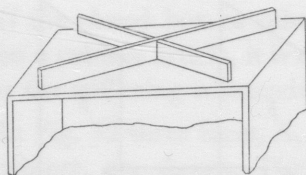


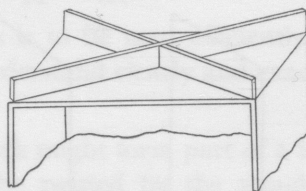
FIG. 37. Relative movement of "A" and "B" not fully restricted.

Similar rules apply to the other methods of making a panel difficult to twist. For instance, the crossed-rib reinforcement shown in Fig. 38



The ends of the reinforcement stop short of the end panels.

FIG. 38. Wrong.



The ends of the reinforcement extend to the end panels.

FIG. 39. Right.

will not be fully effective, as the reinforcing ribs do not extend to the ends. The arrangement shown in Fig. 39, however, would be quite effective.

CHAPTER II

HOW TO MEASURE CABINET RIGIDITY

In applying the principles described in Chapter I, designers and manufacturers will find that improvement of rigidity and more efficient application of the principles will be greatly assisted if the rigidities of prototypes, etc., are measured systematically and the results recorded. The effects on the rigidity of subsequent modifications may then be readily found.

DIFFERENT WAYS OF DEFINING RIGIDITY

As has already been shown, open boxes, when subjected to various types of twisting process, will always deform into the same shape. This is a property of open boxes which enables us to use any one of a number of different systems of forces to measure their overall rigidity. Two convenient alternative systems are shown in Fig. 40.

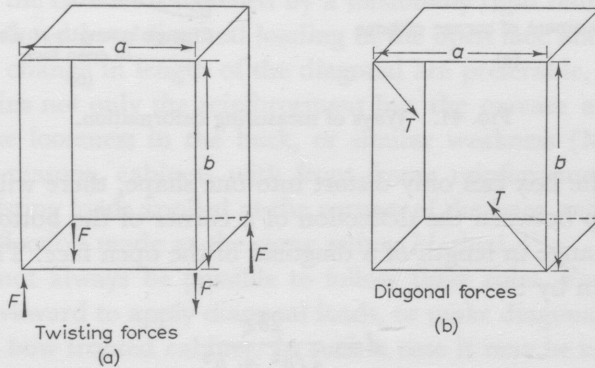


FIG. 40. Ways of applying deforming forces.

In one of these (Fig. 40a), twisting forces, F , are applied at the corners of one side. In the other (Fig. 40b), forces, T , are applied inwards along a diagonal of the open face, distorting it into a diamond

shape. The relationship between the two equivalent systems of forces to produce the same distortion is given by the formula

$$T = \frac{1}{2} \frac{F}{b} \sqrt{a^2 + b^2}$$

where T = diagonal force

F = twisting force on top or bottom

b = height of the open face

a = width of the open face

Having considered the ways of applying deforming forces, we must now choose a means of measuring the deformation of the box. Two convenient means are shown in Fig. 41. In the first of these (Fig. 41a), the deformation of the twisted box is defined by the amount one corner of one side, preferably the base, is deflected out of the plane of the other three corners. In the other method (Fig. 41b), the change in the length of one of the diagonals of the open face is measured.

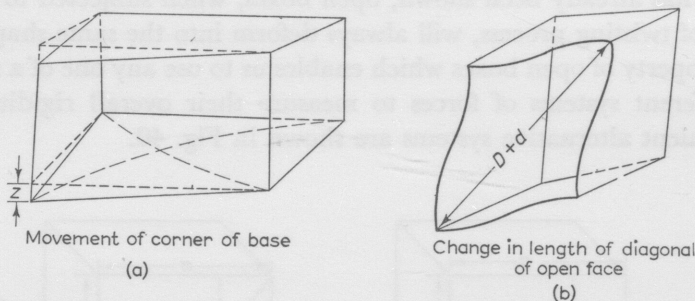


FIG. 41. Ways of measuring deformation.

Since the box can only distort into one shape, there will be a fixed relationship between the deflection of a corner of the bottom (or top) and the change in length of a diagonal of the open face. This relationship is given by :

$$d = \frac{2bz}{\sqrt{a^2 + b^2}}$$

where d = change in length of the diagonal

z = deflection of one corner of the bottom

b = height of open face

a = width of open face

Thus we have two ways of loading the box and two ways of measuring the resulting deformation. The rigidity of the box may then be defined as a load divided by a deformation, and it will be seen that there are four possible ways of doing this :

1. $T \div d$: the load is applied diagonally to the open face and the change in length of the diagonal measured.
2. $T \div z$: the load is applied diagonally to the open face, and the deflection of one corner of the bottom is measured.
3. $F \div d$: the load is applied to the corners of the bottom and the change in length of the diagonal measured.
4. $F \div z$: the load is applied to the corners of the bottom and the deflection of one corner of the bottom is measured.

The two important methods are Nos. 1 and 4, and it is unlikely that 2 or 3 would be used, except in special circumstances, mentioned below.

Each way of measuring rigidity has its advantages in specific cases. For instance, although it has been stated that an open box can only deform into one shape whatever the system of loading applied, this is only so provided there is no play in joints between the panels. For example, if the back of the box fits only loosely in grooves, the back will behave, within limits, like a second open face, with consequent loss of rigidity. In this case the relationships given above do not apply and the method chosen should be that which reveals the looseness in the back. If the cabinet is stiffened by a torsionally rigid reinforcement, such as the closed box, diagonal loading of the open face and measurement of the change in length of the diagonal are preferable, since such loading strains not only the reinforcement but the carcass as a whole, revealing the looseness in the back, or similar weakness (Method 1). For similar reasons, cabinets with front frame reinforcements should have the twisting loads applied at the corners of the base and measurements of deflection made at the same point (Method 4).

It may not always be possible to follow these rules. For instance, it may be awkward to apply diagonal loads, or make diagonal measurements, on a bow fronted cabinet. In such a case it may be necessary to measure the rigidity in a way other than that recommended above. Great care should be taken in such circumstances that there is no looseness in any joint between the faces, or, if such looseness is unavoidable, that it is measured and taken into consideration in making comparisons of stiffnesses.

Suggested methods of measuring the rigidities 1 and 4 are as follows:

1. *Diagonal rigidity* (Method 1)—In this method a load is applied diagonally to the open face, and the change in length of the other diagonal is measured. This may be done in the way shown in Fig. 42a. A length of strong, inextensible wire, such as piano wire, is attached to a spring balance reading up to about 50 lb, and the free end is attached to a turnbuckle. The free end of the spring balance is attached to one corner of the open face and the turnbuckle fixed to the opposite corner. Diagonal loads may then be applied to the open face by tightening the turnbuckle, the value of load being given by the spring balance reading. The resulting deformation may be measured by means of a similar wire stretched across the other diagonal and attached to the tension side of the plunger of a micrometer dial gauge, which is fixed to the other corner of the open face. By plotting values of load against dial gauge readings the stiffness of the carcase is given by the slope ($T \div d$) of the straight line drawn through these points (see Fig. 42b).

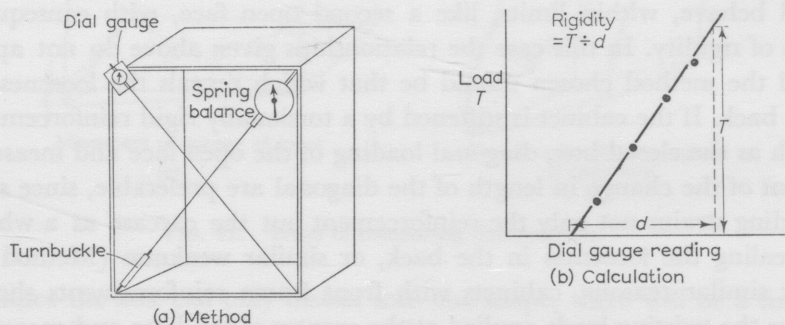
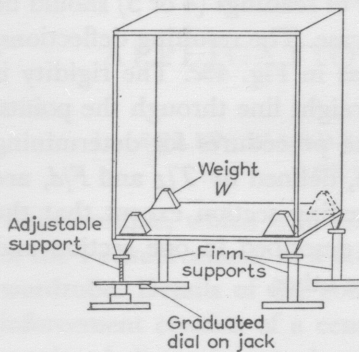


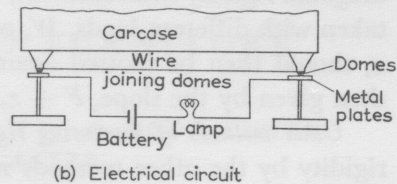
FIG. 42. Diagonal rigidity.

2. *Torsional rigidity* (Method 4)—In this method, the load is applied to the corners of the bottom and the deflection of one corner is measured. A suitable apparatus is shown in Fig. 43a. This consists of four supports, of which one is adjustable. This adjustable support is fitted with a suitable device, such as the screw jack and graduated dial shown, to measure its vertical movement accurately. Electrical equipment is also

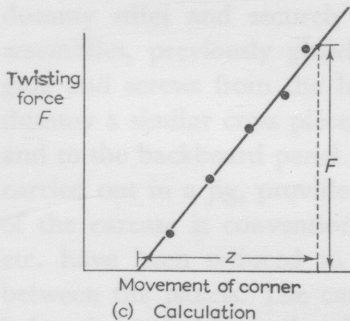
useful to indicate loss of contact between the cabinet and one of the fixed supports (see Fig. 43*b*). Similar equipment is described in detail in BS 1960 : Part 2 : 1953 "Cabinet Goods for Storage Purposes".*



(a) Method (see also BS 1960: Part 2:1953)



(b) Electrical circuit



(c) Calculation

$$F = W + \frac{1}{4}(\text{weight of carcase})$$

$$z = \frac{1}{2}(\text{Difference in readings on jack})$$

$$\text{Rigidity} = F \div z$$

FIG. 43. Torsional rigidity.

The cabinet is set up on the four supports with the electric circuit connected between the rear legs. Four weights are placed in the corners on the bottom of the cabinet. The moveable support is raised by turning the graduated disc until one of the rear legs begins to lift from its support. This is indicated by the extinguishing of the lamp. At that moment the reading on the disc of the screw jack is noted. The jack is then lowered until the other rear leg begins to lift from its support, as indicated by the lamp, and the reading on the jack is again noted.

* Obtainable from British Standards Institution, 2 Park St., London, W.1. Price 5/-.

The difference between the readings is equal to *twice* the deflection of the corner from its unstressed position, and should, therefore, be halved to give the correct value of corner drop, z . The twisting force, F , is equal to the value of the weight placed over each leg, W , plus one-quarter of the weight of the unloaded carcass. As in the case of the diagonal rigidity measurement, a number of readings (4 or 5) should be taken with different loads, W , on the carcass. The resulting deflections, z , should then be plotted against load, as in Fig. 43c. The rigidity is then given by the slope, $F \div z$, of the straight line through the points.

Other methods of measuring rigidity—The procedures for determining rigidity by the other methods mentioned, defined by T/z and F/d , are the same as those described in the preceding section except that the method of application of the load is as described in one section and the measurement of deformation as in the other.

CHAPTER III

APPLICATIONS TO FURNITURE

1. SPLIT WARDROBE, 4 FT. 2 DOOR, WITH CENTRE PILASTER

This example, which is in full scale production, shows the application of the I reinforcement to a fairly typical low priced 4-ft ladies' hanging wardrobe. Details of the construction are shown in Fig. 44. The reinforcement consists of a centre dummy made from two stiles of conventional dimensions and a curved veneered plywood front. At the bottom a cross piece, $1\frac{1}{4}$ in. deep by 36 in. wide, is recessed into the dummy stiles and securely glued and screwed. The shaped plinth assemblies, previously glued up, are attached to the cross piece by glue and screws from the back of the cross piece. At the top of the dummy a similar cross piece is glued and screwed to the dummy stiles and to the backboard panel. The whole sub-assembly, which is quickly carried out in a jig, provides a rigid I-shaped reinforcement. The rest of the carcass is conventional in its construction except that linings etc. have been reduced to a minimum consistent with good joints between the panels. The carcass is split in the normal way, the two halves being held together by a simple tie at the back and by the I reinforcement sub-assembly at the front, the front rails of the top and bottom being fixed to the top and bottom cross pieces by means of screws. (*By courtesy of Alstons (Long Melford) Ltd.*)

2. KNOCKDOWN WARDROBE, 4 FT, 2 DOOR, WITH NO PILASTERS

This wardrobe is an example of the way in which a stiff, strong wardrobe may be made using knockdown construction. The design of the wardrobe is extremely simple, consisting of a closed box for the base, with skins of 6-mm plywood. The two ends and the top are of

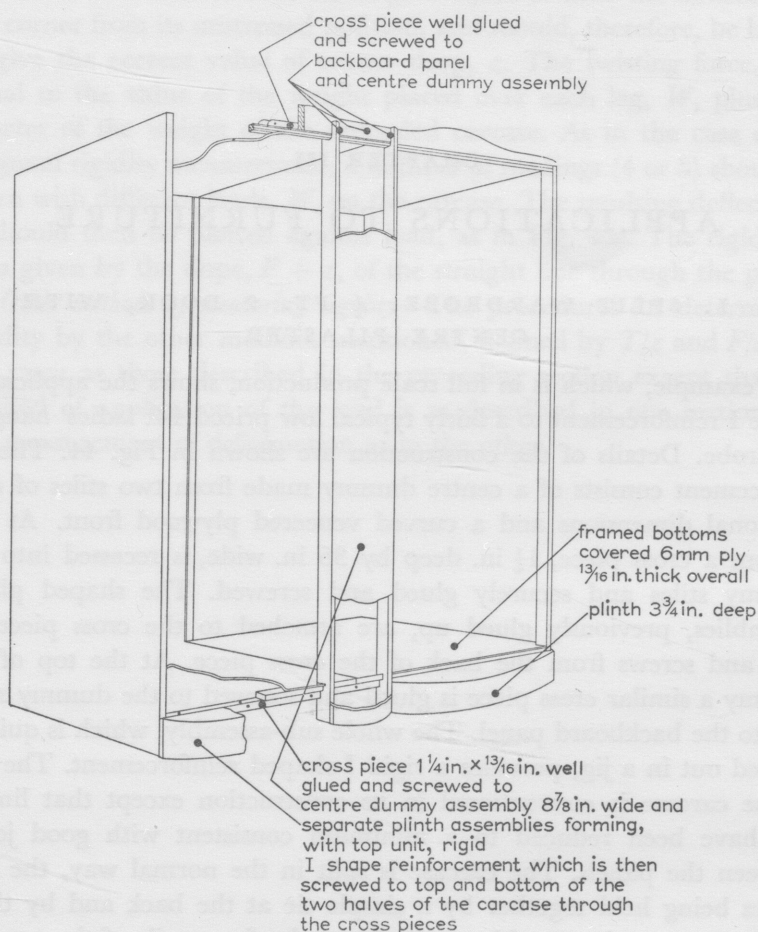


FIG. 44.

$\frac{3}{4}$ -in. chipboard, lipped as shown. The closed box base has an extra member glued to it which is bevelled at the top. Into this bevel the end of the wardrobe fits and is held in position by the knockdown fittings as shown in Fig. 45. The plywood bottom of the box is raised slightly from the floor to allow a handhold when moving the wardrobe. The top is attached to the ends by means of knockdown fittings as shown, and the back, which is of 4-mm plywood, is simply screwed into a rebate in the ends and top, and directly into the back of the closed

box at the bottom of the carcass. The carcass, considering its simplicity, and lack of pilasters, corner braces, etc., is remarkably stiff. (*By courtesy of Meredew Ltd.*)

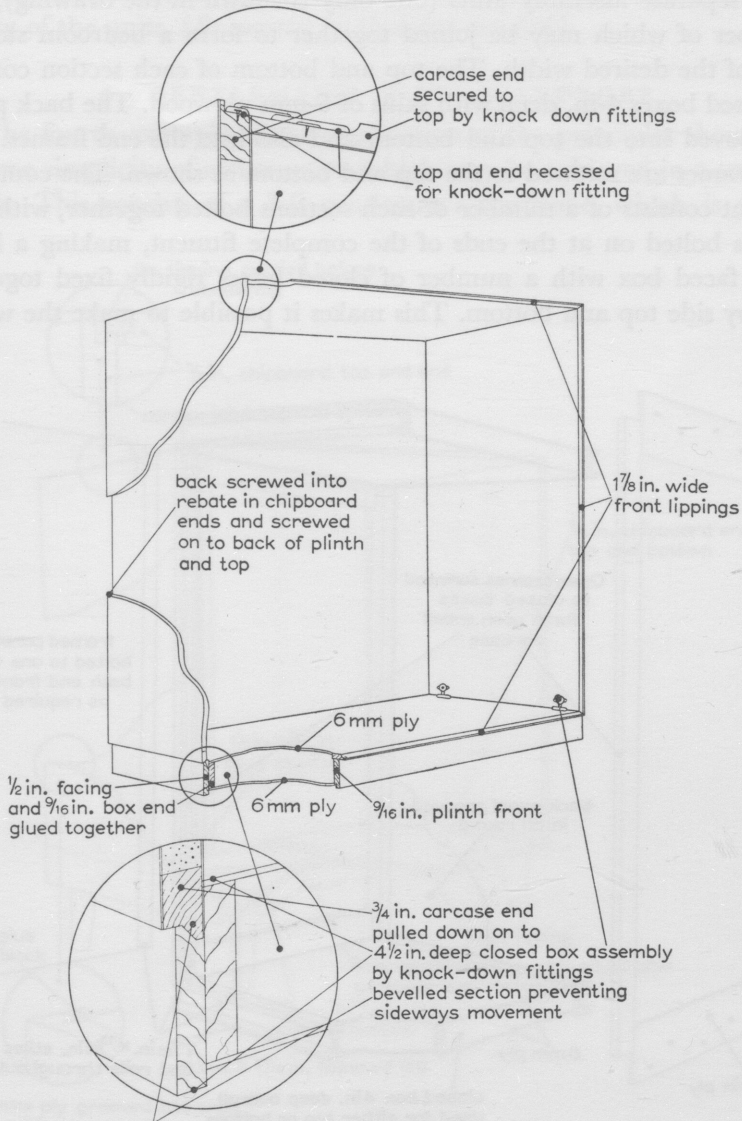


FIG. 45.

3. SECTIONAL WARDROBE IN 2-FT. UNITS

The third example, details of which are shown in Fig. 46, shows an interesting and novel application of the torsionally stiff closed box reinforcement. The article shown is an extendable wardrobe made from separate assembly units (one only is shown in the drawing), any number of which may be joined together to form a bedroom storage unit of the desired width. The top and bottom of each section consists of closed boxes 4-in. deep with skins of 6-mm plywood. The back panel is grooved into the top and bottom and also into the end frames. The end frames are screwed to the top and bottom as shown. The complete fitment consists of a number of such sections bolted together, with end panels bolted on at the ends of the complete fitment, making a large open faced box with a number of closed boxes rigidly fixed together side by side top and bottom. This makes it possible to make the whole

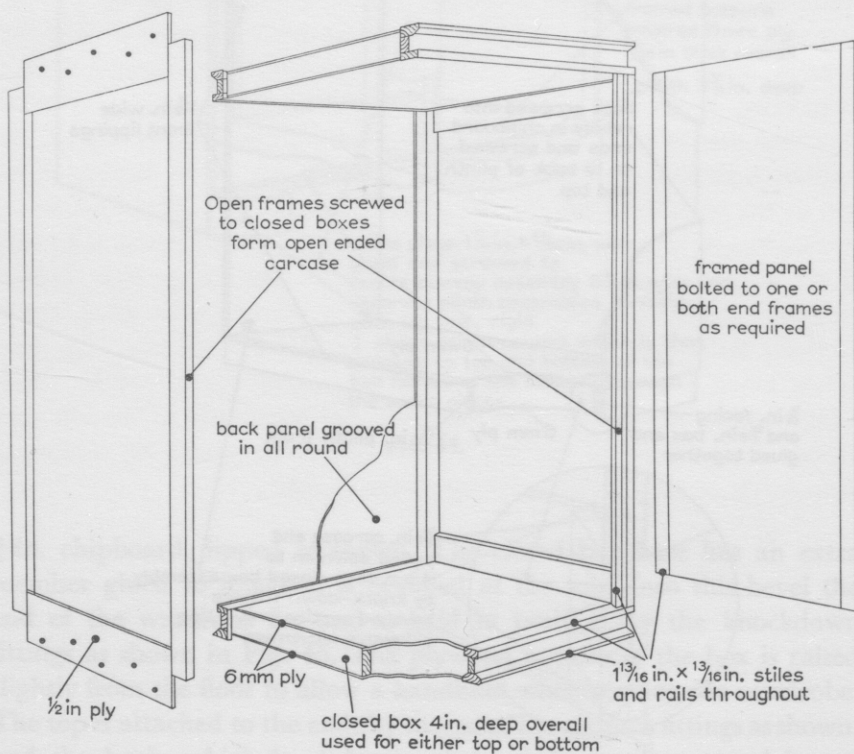


FIG. 46.

fitment firm and rigid, a problem which would be difficult to solve by conventional methods without excessive expenditure of material. It has been pointed out that the torsional stiffening of one side only is sufficient to give stiffness. The closed boxes are put at the top and bottom of each unit in this case, however, for the sake of interchangeability of the units. (*By courtesy of Heal and Son Ltd.*)

4. GENTLEMAN'S 3-FT. WARDROBE

The fourth example of the application of the principles shows the extreme simplicity of construction which may be achieved in a smaller article. This consists of a 3-ft gentleman's wardrobe, which is made

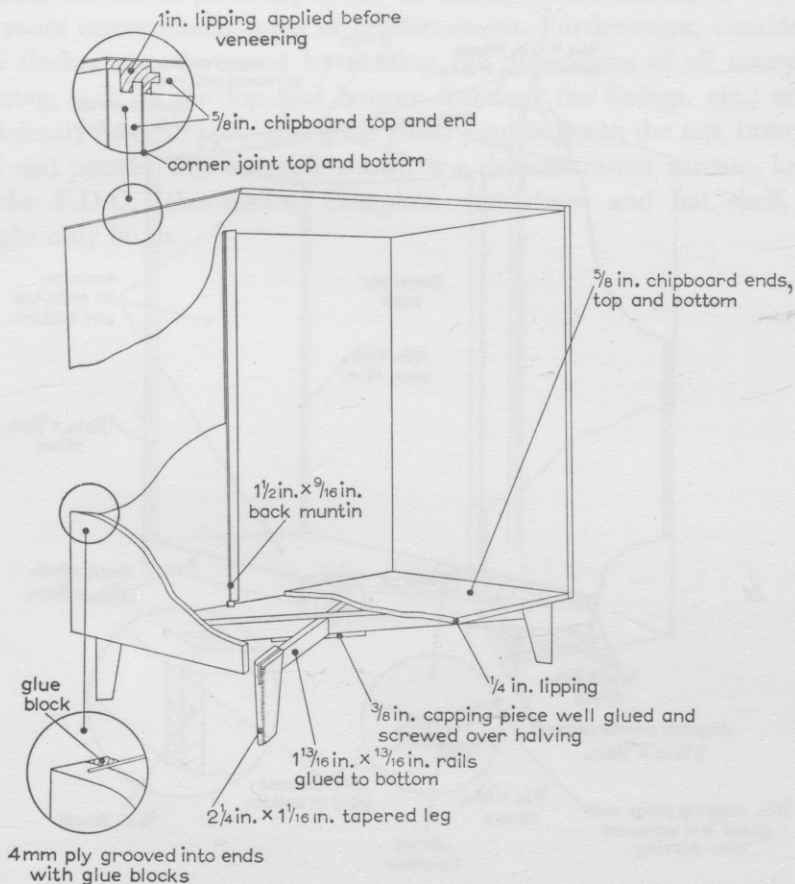


FIG. 47.

mainly from $\frac{5}{8}$ -in. chipboard. On the bottom a single crossed rib reinforcement is used and this is sufficient to give the article a very high degree of rigidity. Details of the construction are shown in Fig. 47. Doors and interior fittings are not shown as these do not affect the general carcass structure.

It will be noted that glue blocks are used to hold the back tight in the grooves. If the back were free to move in the grooves, some of the rigidity of the carcass would be lost. This wardrobe is an experimental model made by a firm of chipboard manufacturers. (*By courtesy of Aircscrew Company and Jicwood Ltd.*)

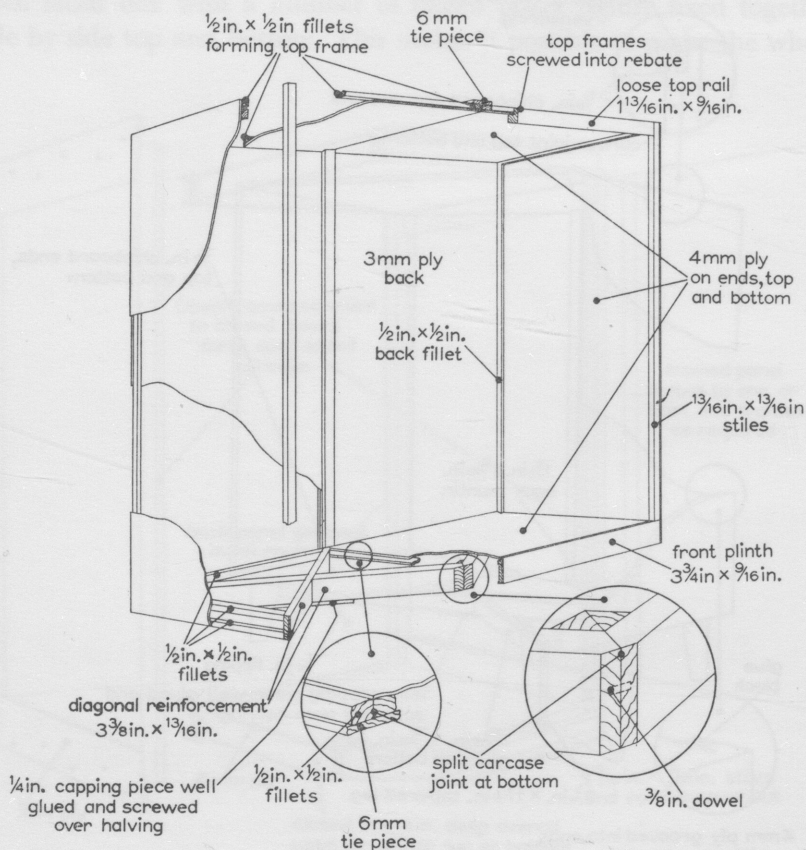


FIG. 48.

5. SPLIT WARDROBE, 4-FT. 2 DOOR, WITH NO PILASTERS

This last example shows an application of the work to the very common frame and plywood type of construction frequently used in making inexpensive wardrobes and similar articles. The construction is shown in Fig. 48. It consists of a split carcass wardrobe with a double crossed rib reinforcement, two cross ribs being glued to each half of the bottom. The two halves then fit together by dry dowels, which should be a tight fit to prevent relative movement of the two halves, and are held together by conventional tie pieces. This reinforcement is sufficient to provide the whole carcass with a high degree of rigidity without the use of pilasters, centre dummies, corner braces, or any of the more conventional types of reinforcement. Furthermore, considerable timber may be saved by making the dimensions of all internal framing, such as the top and bottom framing, the linings, etc., only sufficiently large to provide a good glued joint between the top, bottom and end panels. The example shown is a demonstration carcass, kept at the F.D.C. laboratories. Complete with doors and hat shelf, it weighs only 60 lb.

CHAPTER IV

SOME STIFFNESS CALCULATIONS

The two main principles involved in making stiff cabinets, together with examples of the various ways of putting these principles into practice, have been described earlier in this book. No attempts have been made, however, to work out the stiffness of a particular carcass from its design and from a knowledge of the properties of the materials from which it is made.

In this chapter some of the mathematics that established these principles are discussed and methods of calculating stiffness are shown. The full mathematical analysis that formed the basis of the research project is given in "The Theoretical and Experimental Analysis of Cabinet Structures" (FDC Research Report 6) by T. Kotas, M.Sc. There is, however, nothing in this chapter which has not been discussed earlier in a qualitative way.

I. STIFFENING OF CABINETS BY FRONT FRAMES

As has already been shown, one way of stiffening a five sided open box is by means of a frame fitted into its open face. The object of the frame is to restrain the open face from distorting into a diamond shape, and consequently to keep the box as a whole undeformed. Although there are a large number of frames only the six main types will be discussed. They are:

1. Rectangular frame
2. "T" frame
3. "U" frame
4. "L" frame
5. "I" frame
6. "H" frame.

These frames will be assumed to be made of solid timber members having rectangular cross-sections, and the joints between them will be assumed to be perfectly rigid.

In actual frames no joint would be perfectly rigid, so that the formulae quoted below may give a slightly optimistic estimate of stiffness. The assumption, however, greatly simplifies the calculations and does not seriously affect comparisons between frames based on these calculations.

1. Rectangular frame

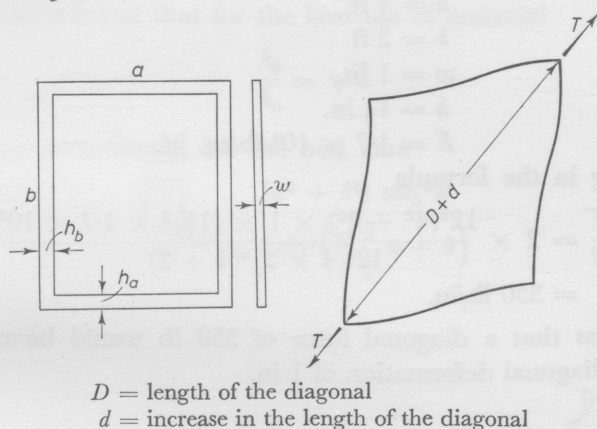


FIG. 49.

If a frame is subjected to diagonal tension or compression, T , then its diagonals of length D change their lengths by d . The ratio T/d defines the diagonal rigidity of the frame. Then, for the rectangular frame,

$$\frac{T}{d} = \frac{24(a^2 + b^2)}{a^2 b^2} \times \frac{1}{\left[\frac{a}{B_a} + \frac{b}{B_b} \right]}$$

where B_a and B_b are the bending stiffnesses of the frame members a and b .

If w is the thickness of frame members, E is Young's Modulus in bending along the grain and h_a and h_b the corresponding widths, then

$$B_a = \frac{w h_a^3}{12} E \quad \text{and} \quad B_b = \frac{w h_b^3}{12} E$$

It has been found from theoretical considerations that for the best use of the material the frame should be made from members of the same cross-section (i.e. $h_a = h_b = h$).

Hence, in such a case, the stiffness

$$\left(\frac{T}{d}\right)_{\text{opt}} = \frac{2(a^2 + b^2) wh^3 E}{a^2 b^2 (a + b)}$$

For a numerical example to show how the stiffness of a frame is actually calculated consider a rectangular frame of beech having the following particulars:

$$a = 4 \text{ ft}$$

$$b = 2 \text{ ft}$$

$$w = 1 \text{ in.}$$

$$h = 1\frac{1}{2} \text{ in.}$$

$$E = 1.7 \times 10^6 \text{ lb/sq. in.}$$

Substituting in the formula

$$\begin{aligned} \frac{T}{d} &= 2 \times \frac{12^2(4^2 + 2^2) \times 1 \times (1\frac{1}{2})^3 \times 1.7 \times 10^6}{12^5(4 \times 2)^2(4 + 2)} \\ &= 350 \text{ lb/in.} \end{aligned}$$

which means that a diagonal force of 350 lb would be required to produce a diagonal deformation of 1 in.

2. "T" frame

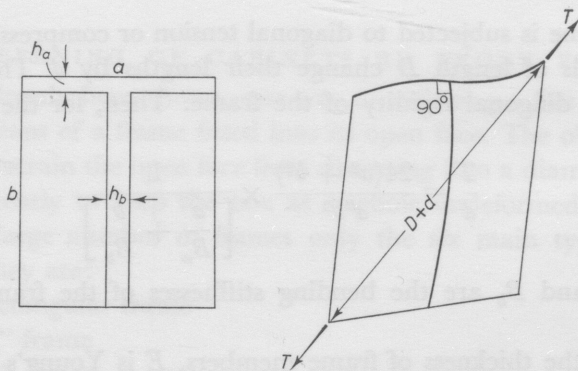


FIG. 50.

The frame consists of two main members forming a letter T. To complete the rectangle three further members may be added but these are assumed to be so light that they contribute little to the stiffness of the structure.

Assuming the upright is in the middle, the expression for stiffness, obtained from theoretical considerations, is

$$\frac{T}{d} = \frac{3(a^2 + b^2)}{a^2 b^2} \times \frac{1}{\left(\frac{a}{4B_a} + \frac{b}{B_b}\right)}$$

the meanings of symbols being as before.

It has been found that for the best use of material

$$\frac{h_b}{h_a} = \sqrt{2}$$

Substituting accordingly, for the best case

$$\left(\frac{T}{d}\right)_{\text{opt}} = \frac{(a^2 + b^2) w h_b^3 E}{4a^2 b^2 \left(\frac{\sqrt{2}}{2} a + b\right)}$$

3. "U" frame

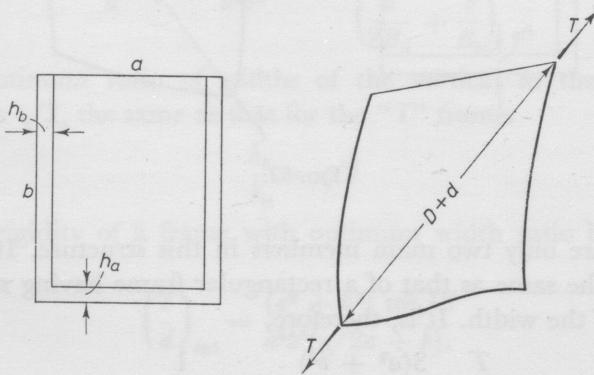


FIG. 51.

There are three main members in this structure, the fourth being a light strut of negligible bending stiffness. The expression for the diagonal rigidity of this structure is

$$\frac{T}{d} = \frac{6(a^2 + b^2)}{a^2 b^2} \times \frac{1}{\left(\frac{a}{2B_a} + \frac{b}{B_b}\right)}$$

the notation being the same as above.

The relationship between the widths of the vertical and the horizontal members for the best use of the material is, as with the rectangular frame,

$$h_b = h_a = h$$

in which case the stiffness will be

$$\left(\frac{T}{d}\right)_{\text{opt}} = \frac{(a^2 + b^2) wh^3 E}{a^2 b^2 (2b + a)}$$

4. "L" frame

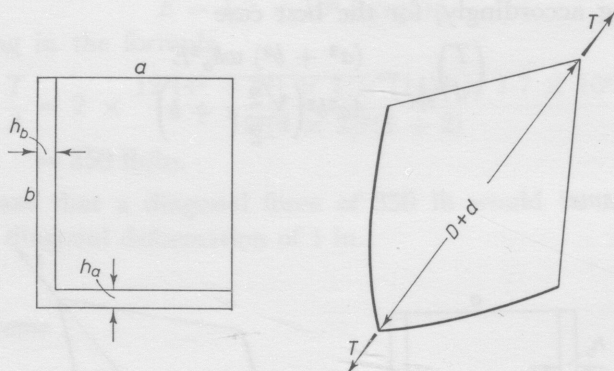


FIG. 52.

There are only two main members in this structure. Its diagonal stiffness is the same as that of a rectangular frame having main members of half the width. It is, therefore,

$$\frac{T}{d} = \frac{3(a^2 + b^2)}{a^2 b^2} \times \frac{1}{\left(\frac{a}{B_a} + \frac{b}{B_b}\right)}$$

Also, as in the case of a rectangular frame, the main members should have, for the best use of the material, the same cross-sections, i.e.

$$h_a = h_b = h$$

and the corresponding diagonal stiffness will be

$$\left(\frac{T}{d}\right)_{\text{opt}} = \frac{(a^2 + b^2) wh^3 E}{4a^2 b^2 (a + b)}$$

5. "I" frame

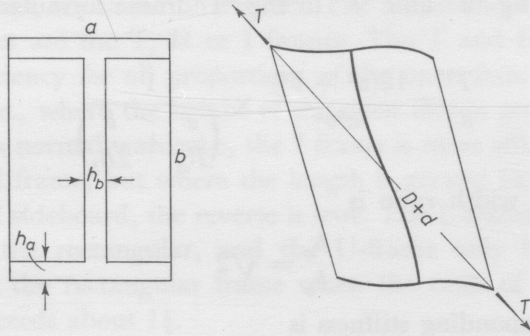


FIG. 53.

This reinforcing frame is similar to the "T" frame but has an extra cross-piece. Again, assuming the upright is in the middle, its stiffness is given by

$$\frac{T}{d} = \frac{12(a^2 + b^2)}{a^2 b^2} \times \frac{1}{\left(\frac{a}{2B_a} + \frac{b}{B_b}\right)}$$

The optimum ratio of widths of the vertical to the horizontal members is $\sqrt{2}$, the same as that for the "T" frame.

i.e.

$$\frac{h_b}{h_a} = \sqrt{2}$$

Thus the rigidity of a frame with optimum width ratio between the members,

$$\left(\frac{T}{d}\right)_{\text{opt}} = \frac{(a^2 + b^2) w h_b^3 E}{a^2 b^2 (\sqrt{2}a + b)}.$$

6. "H" frame

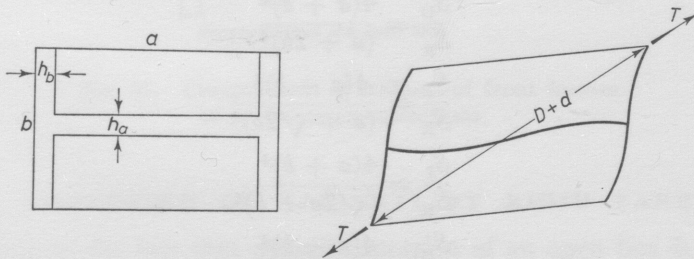


FIG. 54.

— This reinforcement is simply the “I” frame turned on its side, so that, transposing “ a ” and “ b ” in the “I” frame formulae, the stiffness is given by

$$\frac{T}{d} = \frac{12(a^2 + b^2)}{a^2 b^2} \times \frac{1}{\left(\frac{a}{B_a} + \frac{b}{2B_b}\right)}$$

The optimum width ratio is

$$\frac{h_a}{h_b} = \sqrt{2}$$

And the corresponding stiffness is

$$\left(\frac{T}{d}\right)_{\text{opt}} = \frac{(a^2 + b^2) w h_a^3 E}{a^2 b^2 (a + \sqrt{2} b)}$$

Comparison of frame rigidities for the same material content

The six frames discussed are not equally effective in resisting diagonal forces. In particular, their relative efficiencies will depend on their dimensions, and on the proportions of the open face they are meant to reinforce. If we assume, however, that they all have the same material content, and are all made of members of the same thickness, w , it is possible to work out their relative effectiveness for a given amount of material. Taking the optimum width ratios for the members in each case, and taking the rectangular frame as the standard of comparison, we can calculate the stiffnesses, S , of the L, U, T, I and H frames relative to the rectangular frame and obtain the following:

$$\frac{S_L}{S_R} = 1$$

$$\frac{S_U}{S_R} = \frac{4(a + b)^4}{(a + 2b)^4}$$

$$\frac{S_T}{S_R} = \frac{4(a + b)^4}{(a + \sqrt{2}b)^4}$$

$$\frac{S_I}{S_R} = \frac{4(a + b)^4}{(\sqrt{2}a + b)^4}$$

$$\frac{S_H}{S_R} = \frac{4(a + b)^4}{(a + \sqrt{2}b)^4}$$

These relations, plotted against the ratio of the length to height of the frame, a/b , are shown in Fig. 55. The results show that the most efficient frames are the T, H or I frames. The T and H frames have the same efficiency for all proportions of the open face. Where a/b is less than 1, i.e., where the height of the open face is greater than the length, as in a normal wardrobe, the I frame is more efficient than the T frame or H frame, but where the length is greater than the height, as in a typical sideboard, the reverse is true. The L-frame has the same efficiency as the rectangular, and the U-frame only becomes more efficient than the rectangular frame when the ratio of the length to the height exceeds about $1\frac{1}{2}$.

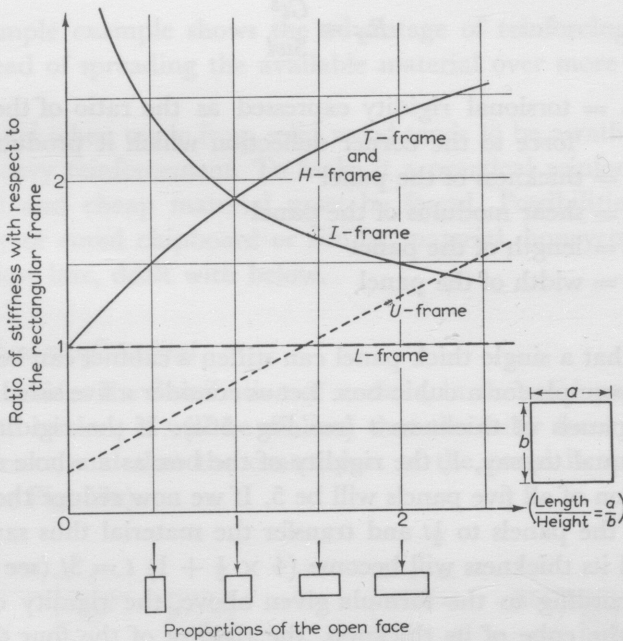


Fig. 55. Comparisons of stiffness of front frames of optimum cross-sections.

2. STIFFENING OF CABINETS BY RIGID PANELS

Owing to the fact that overall distortion of an open box is always accompanied by the twisting of all its faces, we can stiffen the box by

making one or more of its faces resistant to twisting forces. The way in which the torsional rigidity of one panel affects the overall rigidity of the box is shown in the next section. In the following four subsections the main characteristics of the panel reinforcements themselves will be discussed.

1. *Solid panel reinforcement*

A cabinet can be stiffened by making one of its panels very thick. The formula for the torsional rigidity of a solid uniform rectangular panel is

$$R_T = \frac{Gt^3}{3wl}$$

where R_T = torsional rigidity expressed as the ratio of the torsional force to the corner deflection which it produces (F/z).

t = thickness of the panel

G = shear modulus of the panel

l = length of the panel

w = width of the panel

The fact that a single thick panel can stiffen a cabinet can be shown by a simple example for a cubic box. Let us consider a five sided box made up from panels of thickness t (see Fig. 56a). If the rigidity of each panel is equal to, say, 1, the rigidity of the box as a whole due to the contribution of all five panels will be 5. If we now reduce the thickness of four of the panels to $\frac{1}{2}t$ and transfer the material thus saved to the fifth panel its thickness will become $(4 \times \frac{1}{2} + 1)t = 3t$ (see Fig. 56b). Since, according to the formula given above, the rigidity of a panel varies as the cube of its thickness, the rigidity of the four thin panels will be reduced to $(\frac{1}{2})^3 = \frac{1}{8}$ and that of the thick panel increased to $(3)^3 = 27$. The overall rigidity of the modified box, therefore, will be $4 \times \frac{1}{8} + 27 = 27\frac{1}{2}$. Thus the rigidity of the box due to the redistribution of the material of the box will increase in the ratio

$$\frac{27\frac{1}{2}}{5} = 5\frac{1}{2} \text{ times.}$$

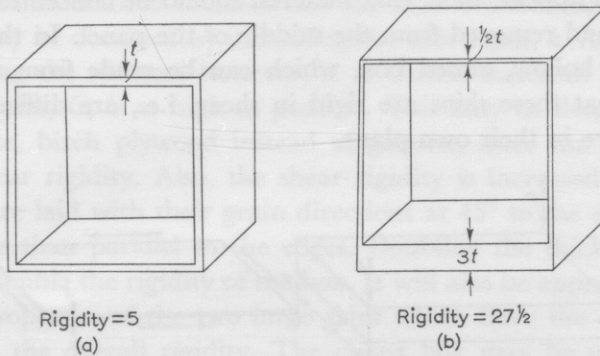


FIG. 56.

This simple example shows the advantage of reinforcing a single panel instead of spreading the available material over more than one panel.

The panel when made from solid wood tends to be a rather expensive and heavy reinforcement. To make it a practical reinforcement a light, rigid and cheap material must be found. Possibilities include low density or cored chipboard or similar material, honeycomb cores, or the hollow box, dealt with below.

2. Closed box reinforcement

If we consider the distribution of stress, s , in the solid panel when subjected to torsion, it will be realised that the outer faces carry the highest stresses, and that the centre part of the panel is only lightly stressed (see Fig. 57a).

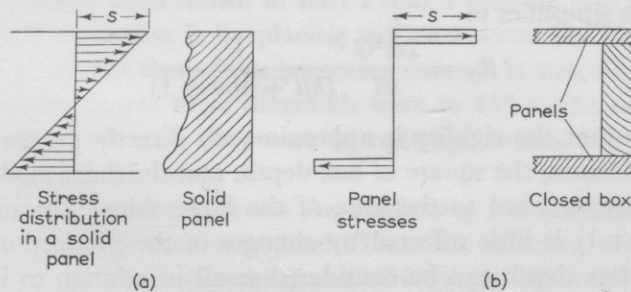


FIG. 57. Stress distribution.

It would appear, then, that material should be concentrated at the outer face and removed from the middle of the panel. In this way we arrive at a hollow, closed box, which can be made from thin skins, provided that these skins are rigid in shear, i.e., are difficult to pull out of square in their own plane.

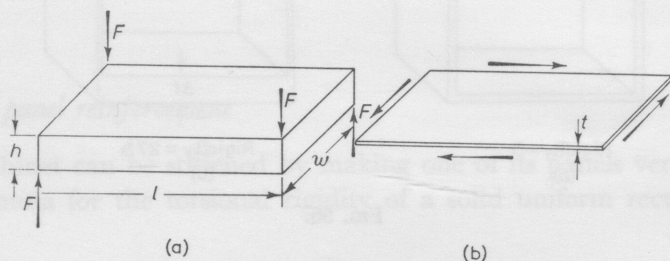


FIG. 58.

Referring to Fig. 58, the torsional rigidity of a box whose opposite skins are identical, is

$$R_T = \frac{F}{z} = \frac{2h^2}{\frac{wh}{t_{wh} G_{wh}} + \frac{lh}{t_{lh} G_{lh}} + \frac{wl}{t_{wl} G_{wl}}}$$

where G = shear rigidity of the skin

z = corner deflection of the box in the direction of force F

The meaning of the other symbols is indicated in the diagram above. If the box is made from skins of the same thickness and having the same shear rigidity so that

$$t_{wh} = t_{lh} = t_{wl} = t$$

and

$$G_{wh} = G_{lh} = G_{wl} = G$$

the formula simplifies to

$$R_T = \frac{2th^2G}{wl} \frac{1}{(h/l + h/w + 1)}$$

This shows that the rigidity is approximately directly proportional to the skin thickness, the square of box depth, and the shear modulus, but inversely proportional to the area of the large skins. The expression $(h/l + h/w + 1)$ is little affected by changes in the proportions of the box if the box depth can be considered small in relation to its length and width.

These considerations indicate that the most economical increase in stiffness may be obtained by increasing the box depth, h . Another way of increasing the stiffness, however, is to choose materials so that the shear modulus, G , is as high as possible. This may be done by using, for instance, birch plywood instead of gaboony, since the former has greater shear rigidity. Also, the shear rigidity is increased fourfold if the skins are laid with their grain directions at 45° to the edges of the box, rather than parallel to the edges. Doubling the thickness of the skins will double the rigidity of the box. It will also be appreciated that it is the properties of the two large skins which have the decisive influence on the overall rigidity. The closed box may be used in two parts without any appreciable loss of rigidity (see Fig. 59).

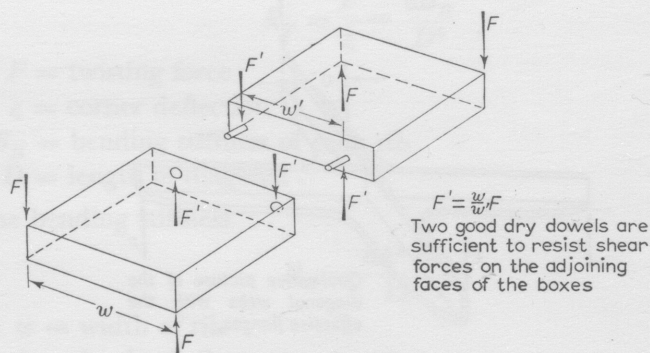


FIG. 59. Split closed box reinforcement.

3. Crossed-rib reinforcement

It has already been shown in Part I that a possible way of making a panel rigid in torsion is by placing stiff ribs across the diagonals of the panel to prevent them from becoming curved. It was, furthermore, shown that the nearer these diagonals were to 45° to the edge of the panel the more effective they were in resisting torsion. We will now consider this in more detail.

In resisting the twisting forces the reinforcing ribs act together with the panel to which they are glued. Thus the effective cross-section resisting bending is actually composed of a flange which is formed by the panel and a web which is formed by the rib.

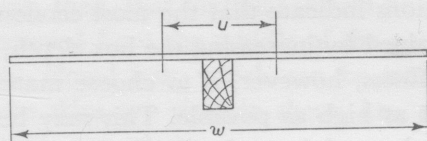


FIG. 60.

In calculating the bending stiffness of this combination, however, the effective width, u , of the plywood flange is considerably less than the actual width, w , due to the fact that the stress in the flange decreases steadily between the web and the edge of the flange. An idealised diagram of the effective part of the rib-panel combination is shown in Fig. 60.

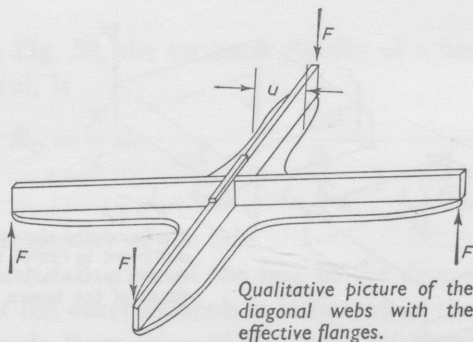


FIG. 61.

Furthermore, the actual value of u varies along the length of the web, increasing towards the middle, and decreasing towards the ends. A qualitative picture of the whole reinforcement will, therefore, be something like that shown in Fig. 61. Unfortunately, such a problem has never been solved mathematically for a flange of plywood. Consequently, we are obliged to obtain an approximate answer by neglecting the effects of the flanges and calculating the reinforcing effects of the webs alone. In experiments carried out, however, it has been found that this gives a reasonable estimate of the rigidity of the whole rib-panel combination, probably because the contribution of the panel approximately balances out the loss of rigidity due to the halved joint at the intersection of the ribs.

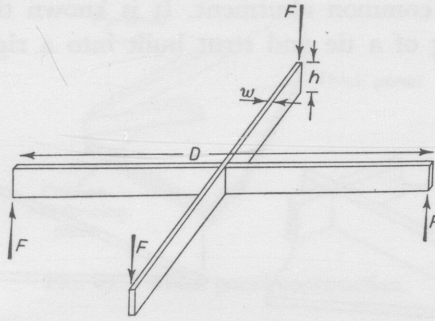


FIG. 62. Simplified crossed-rib reinforcement.

This simplified reinforcement is shown in Fig. 61.

The torsional rigidity of such a combination is given by

$$R_T = \frac{F}{z} = \frac{6B_R}{D^3}$$

where F = twisting force

z = corner deflection

B_R = bending stiffness of each rib

D = length of diagonal

and the bending stiffness

$$B_R = \frac{wh^3 E}{12}$$

where w = width of rib

h = depth of rib

E = Young's modulus in bending.

To increase the rigidity, therefore, it is much more advantageous to increase the depth of the ribs, h , rather than the width, w , since the rigidity varies with h^3 , but only directly with w . It is also advantageous to use wood with a high Young's Modulus. Ramin is a very suitable, inexpensive wood in this respect.

If the double crossed-rib reinforcement is used, the overall corner deflection, z , will be the sum of the individual deflections of the two single reinforcements.

4. Pyramid reinforcement

It can be easily seen from the previous section that a crossed-rib reinforcement loaded by twisting forces can in fact be regarded as four

cantilevers with a common abutment. It is known that a triangular structure consisting of a tie and strut built into a rigid wall is more

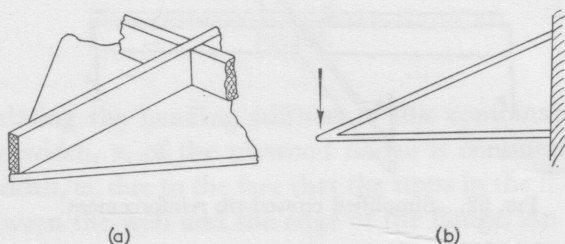


FIG. 63. Cantilevers.

effective in resisting bending forces than a simple cantilever (see Fig. 63). We can, therefore, replace the plain cantilevers in the crossed-rib reinforcement by the above structure, obtaining in consequence a structure which we can call the pyramid reinforcement. This reinforcement consists essentially of four rods arranged along the edges of a pyramid and joining at its apex (see Fig. 64).

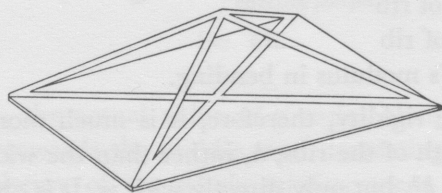


FIG. 64. The pyramid reinforcement.

The base of the pyramid is formed by the panel. If the panel is thin it has to be reinforced diagonally as shown. A thick panel may be sufficient by itself to resist the tensile and compressive forces, and no diagonal reinforcing members will then be required, except, perhaps, at the corners where the effective cross-section of the panel is small (see Fig. 65).

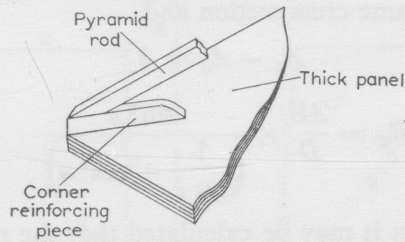


FIG. 65. Thick panel construction.

The formula for the rigidity of the pyramid reinforcement consisting of rods alone, without the panel, is

$$R_T = \frac{E \sin^2 a}{D \left(\frac{1}{A_p \cos a} + \frac{\cos^2 a}{A_d} \right)}$$

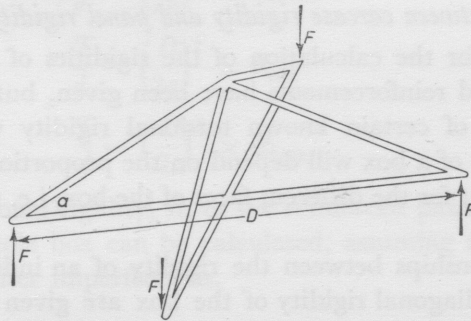


FIG. 66. Forces on pyramid.

where R_T = torsional rigidity of the structure expressed as the ratio of the torsional force to the resulting corner deflection, (F/z)

E = Young's modulus in bending

D = length of the diagonal

a = angle of inclination of the pyramid rods to the diagonal rods

A_p = cross-sectional area of the pyramid rods

A_d = cross-sectional area of the diagonal rods.

If the rods are the same cross section and

$$A_p - A_d = A$$

then

$$R_T = \frac{AE}{D} \times \frac{\sin^2 a}{\left(\frac{1}{\cos a} + \cos^2 a\right)}$$

From the formula it may be calculated that the maximum rigidity occurs when the angle, a , between the pyramid rods and the panel is 60° . Such a large angle is not practicable for most furniture applications. However, even with the much smaller angle of 20° , the rigidity compares well with those of the other torsionally rigid reinforcements considered.

It will be noted that, in calculating the rigidity of the pyramid, it was necessary to make the same assumption as in the case of the crossed-rib reinforcement, namely, that the panel contributes nothing to the stiffness.

Relationship between carcase rigidity and panel rigidity

Formulae for the calculation of the rigidities of different types of torsionally rigid reinforcements have been given, but the effect that a reinforcement of certain known torsional rigidity will have on the overall rigidity of a box will depend on the proportions of the box and will be different for the different faces of the box, i.e. top, bottom, back or end.

The relationships between the rigidity of an individual panel and the resulting diagonal rigidity of the box are given by the following formulae:

$$\frac{T}{d} = \frac{a^2 + b^2}{4b^2} \times R_{\text{bottom}}$$

$$\frac{T}{d} = \frac{a^2 + b^2}{4a^2} \times R_{\text{end}}$$

$$\frac{T}{d} = \frac{a^2 + b^2}{4c^2} \times R_{\text{back}}$$

where a , b , c are the principal dimensions of the box, as shown in Fig. 67, and R_{bottom} , R_{end} , and R_{back} are the torsional rigidities of the reinforced bottom, end or back as defined by the ratio F/z of the torsionally reinforced face.

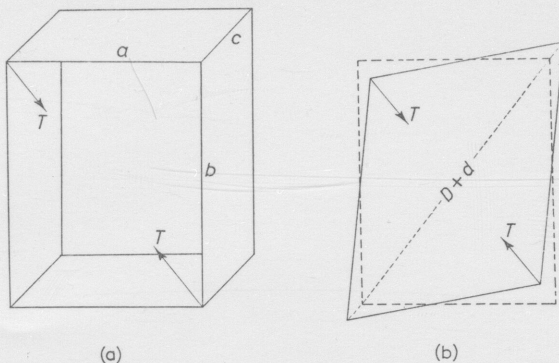


FIG. 67. Deformation of the open face.

It will be noticed that the expression $a^2 + b^2$ appearing in each of the formulae is equal to the square of the diagonal, D , of the open face. Therefore, we can re-write them as follows:

$$\frac{T}{d} = \left(\frac{D}{2b}\right)^2 \times R_{\text{bottom}}$$

$$\frac{T}{d} = \left(\frac{D}{2a}\right)^2 \times R_{\text{end}}$$

$$\frac{T}{d} = \left(\frac{D}{2c}\right)^2 \times R_{\text{back}}$$

Hence if the torsional rigidity, R , of the reinforced panel is known the rigidity of the whole box can be calculated, assuming no loose joints, loose panels or other imperfections.

LORD KELVIN, speaking in 1883 to the Institution of Civil Engineers:

"When you can measure what you are speaking of, and express it in numbers, you know that on which you are discoursing. But when you cannot measure it and express it in numbers, your knowledge is of a very meagre and unsatisfactory kind."